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AUTHOR	Nummedal, Susan; And Others
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ABSTRACT

A project was undertaken to develop and evaluate the effectiveness of a unit of instruction which would teach economically deprived first grade children some interesting scientific concepts and increase their curiosity behavior and willingness to offer hypotheses, carry out experiments, and evaluate outcomes. The instructional unit was based on the concept that all matter living and non-living, is composed of molecules which can undergo change. The unit was presented in two parts. In Part I, six 50-60 minute lessons were presented to an intact class over a two-week period. Comparisons between this experimental group and an uninstructed control class revealed that over the relatively short instructional period the experimental group did significantly better (p.01) on the subject matter test than the control group. On the Banta Curiosity Box Test, both the pretested and non-pretested experimental children and the pretested control children scored significantly higher than the non-pretested control children. The results to the other individual measures developed to assess curiosity behavior were ambiguous, primarily due to problems with the measures themselves. Modification and extension of the instructional program and the evaluation instruments were undertaken in Part II. One month after the completion of Part I, the same experimental class was presented five 30-minute lessons in a seven-week period. Experimental children continued to perform better (p.005) than their control counterparts under the revised instructional program. Results of Parts I and II point up the importance of the further development of instructional units designed to improve young children's scientific inquiry processes. (Author/CK)

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A MODULE FOR TEACHING SCIENTIFIC INQUIRY TECHNIQUES TO FIRST GRADE ECONOMICALLY-DEPRIVED CHILDREN

by

Susan Nummedal, Nome Baker, and Evan Keislar

October, 1971

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ABSTRACT

The goal of this project was to develop and evaluate the effectiveness of a unit of instruction which would teach economically-deprived first grade children some interesting scientific concepts and at the same time increase their curiosity behavior and willingness to offer hypotheses, carry out experiments, and evaluate outcomes.

The instructional unit was based on the concept that all matter, living and non-living, is composed of molecules which can undergo change. The unit was presented in two parts. In Part I, six 50-60 minute lessons were presented to an intact class over a two-week period. Comparisons between this experimental group and an uninstructed control class revealed that over the relatively short instructional period the experimental group did significantly better ($p<.01$) on the subject matter test than the control group. On the Banta Curiosity Box Test, both the pretested and non-pretested experimental children and the pretested control children scored significantly higher than the non-pretested control children. The results of the other individual measures developed to assess curiosity behavior were ambiguous, primarily due to problems with the measures themselves.

Modification and extension of the instructional program and the evaluation instruments were undertaken in Part II. One month after the completion of Part I, the same experimental class was presented five

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30-minute lessons in a seven-week period. During the periods between each of the lessons, the regular classroom teacher conducted two 30-minute sessions based on the material of the unit. The subject matter posttest results showed that the experimental children continued to perform better ($p < .005$) than their control counterparts under the revised instructional program.

The results of Parts I and II point up the importance of the further development of instructional units designed to improve young children's scientific inquiry processes. They also reveal the need for the development of reliable instruments to assess the effectiveness of these units.

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Introduction

During the past decade, considerable effort has been expended by educators, psychologists, and subject matter specialists to develop more effective science curricula for young children. While projects such as the Conceptually Oriented Programs in Elementary Science, Elementary Science Study, Minnesota Mathematics and Science Teaching Project, Science - A Process Approach, and Science Curriculum Improvement Study have focused on teaching concepts and theories that are the products of scientific investigations, they have also placed increasing emphasis on the development of the procedures and attitudes characteristic of the scientific method. This growing concern with the development of processes in young children is reflected in the objectives established in the 1969-70 National Assessment in Science (National Assessment for Educational Progress Newsletter, 1971, p. 2), in which three of the four objectives focused on processes and attitudes, and only one was concerned with scientific products or facts per se:

"(1) Know fundamental facts and principles of science;
(2) Possess the abilities and skills needed to engage in the processes of science;
(3) Understand the investigative nature of science; and
(4) Have attitudes about and appreciations of scientists, science, and the consequences of science that stem from adequate understandings."

Science educators agree that it is important to develop scientific inquiry skills and attitudes in young children; they also acknowledge that it is very difficult to assess the effectiveness of curricula in these goal areas (vide Cunningham, 1966; National Assessment for Educational Progress Newsletter, 1971; and Peterson & Lowery, 1968). Indeed, this difficulty has been underscored in a recent review of evaluative research in science education in which Belanger found that "papers on concept learning in science outnumber papers in other categories" (1969, p. 378). The paucity of studies designed to assess the effectiveness of curricula focusing on various process goals clearly cannot be attributed to lack of concern with these goals but rather to the general unavailability of instrumentation that would be necessary to assess the desired changes. In 1970, a comprehensive evaluation of published tests designed for use with elementary school children revealed that there were no standardized, published instruments to assess scientific processes and/or attitudes in first- and third-grade children. For fifth- and sixth-graders, only two such tests are available, and they are of questionable value in terms of measurement validity and reliability (Hoepfner, 1970). Thus, while there have been several attempts (e.g., Banta, 1968; National Assessment of Educational Progress Newsletter, 1971; Peterson & Lowery, 1968) to develop these much needed instruments, to date very little objective data are available on the extent to which curricular innovations have resulted in children being more curious about the world in which they live or better able to formulate hypotheses, conduct experiments, and evaluate the validity of their hypotheses.

The present investigation attempted to respond to the need for (1) curricula to teach disadvantaged young children the processes involved

in scientific investigation, and (2) assessment procedures which could be used to measure the acquisition of these process skills. Specifically the overall goal of this project was to develop and evaluate the effectiveness of a two-week pilot instructional program designed to teach first-grade children to formulate and test hypotheses and, in a more general sense, to be curious about their physical environment. Thus there were two related components: (1) the two-week pilot instructional program, and (2) the evaluation instruments which would measure the effectiveness of the unit.

Once the pilot testing of the program and evaluation of its effectiveness had been completed, further modification and extension of the instructional program and the evaluation instruments were undertaken. The initial two-week program will be presented in Part I of this report and the extension of that work will be presented in Part II.

PART I

Method

Subjects

Two first-grade classes from an elementary school located in a low socio-economic area of Southern California were used for the study. One was assigned to be the experimental class and the other the control class. There were 27 children (13 boys and 14 girls) in the experimental and 28 children (16 boys and 12 girls) in the control groups. In both classes the mean age was 6.5 years with a standard deviation of .3 years. The experimental class included 11 Blacks and 16 Mexican-Americans while the control class had 7 Blacks, 20 Mexican-Americans, and 1 Oriental. On the Peabody

Picture Vocabulary Test, 21 experimental and 23 control children received I.Q. scores of 89.9 (S.D. 20.9) and 87.6 (S.D. 19.8) respectively.

Instructional Program

During a two-week period, the experimental children were given six 50-60 minute lessons by the second author, a university professor of biochemistry who was also employed in a large research laboratory. The regular classroom teacher observed the lessons from the back of the room, helping the children during the laboratory sessions when necessary.

The aims of the instructional program were as follows:

1) to present a series of lessons which would teach first grade children some interesting scientific concepts organized around a central conceptual scheme, and at the same time increase their curiosity behavior and willingness to offer hypotheses, carry out experiments, evaluate experimental observation, utilize abstract models, and be eager to continue such classes in scholarly inquiry;
2) to develop and test new ways by which the children could participate actively in each scientific experiment, in contrast to having the children passively observe a teacher-presented demonstration; and
3) to obtain video-taped records of the classes for use in evaluation and in the development of shorter, more effective lessons which could be used in a more extensive science program.

Because it is difficult, if not impossible, to separate processes such as hypothesis formation or manipulative exploration from content, it was decided that the lessons of the unit should be based on a

unifying conceptual scheme. The conceptual scheme, based on the subject matter of biochemistry, was:

> All matter, living and non-living, is composed of molecules which can undergo changes.

The component concepts of the scheme were:

(1) Molecules are composed of atoms.

(2) Molecules can change (i.e., react).

(3) Big molecules can be made from smaller molecules.

(4) Smaller molecules can be made from larger molecules.

(5) Molecules are very much smaller than the smallest visible substance, and atoms are even smaller than molecules.

Brief synopses of the content and activities of the six lessons are presented in Appendix A.

Criterion Measures

There were two parts to the evaluation of the effectiveness of the instructional program: (1) a battery of four individually-administered tests, and (2) a subject matter test administered as a group test separately to each class.

The design for the individually-administered measures (Table 1) was basically the Soloman Four-Group Design (Campbell & Stanley, 1963). A randomly selected sub-sample of the experimental class was pretested and posttested (Group 1). The remainder of the class was administered the test battery as a post measure only (Group 3). Likewise, a random subsample of the control class was both pretested and posttested (Group 2), while the rest of the class was posttested only (Group 4). For Group 1, the pretest-posttest interval was an average of 18 days. The testing

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TABLE 1

Design for the Individually Administered Tests

Group	Pretest	Treatment Group	Posttest	N
1	X	Experimental	X	8
2	X	Control	X	8
3		Experimental	X	13
4		Control	X	15

interval for Group 2 was approximately 30 days. Unfortunately, this group's longer testing interval was unavoidable since a two-week holiday period intervened between the testing times.

The design employed allowed for analyses of the main effects of testing and treatment, as well as the interaction of testing and treatment. The need for this information was twofold. First, although the school in which the study was being conducted disclaimed the use of any ability criteria for assigning students to classes, the experimental and control groups were formed from intact classes, and it was important to determine whether the groups were in fact equivalent in terms of general ability and curiosity behavior prior to instruction. Therefore it was essential to administer the pretest. However, pretesting the children raised a second consideration. No short-term (i.e., two-to-three week) test-retest reliability estimates were available for any of the individual measures, nor was it known what the effect of pretesting might be on learning the subject matter of the unit. By pretesting only part of each treatment group, it was possible to determine the nature of the interaction between testing and treatment group.

The individually-administered battery consisted of four tests[1]: (1) the Curiosity Box Test, (2) the Ball Drop Test, (3) the Liquid Change Test, and (4) the Floating Bodies Test. The first three of these measures were employed to determine the effect of the unit on children's curiosity about their physical environment. There were 50 points possible on Test 1, four points possible on Test 2, and seven points possible on Test 3, with the high score meaning the greatest curiosity for each test. The fourth test was used to assess the children's ability to formulate guesses or hypotheses, test their guesses, evaluate the outcome, and remember the outcome. The test yielded three scores (Prediction, Verification, and Re-sorting), with eight points possible on each.

The individual tests were administered to each child in one of two orders: (1) Tests 1, 4, 2, and 3; and (2) Tests 4, 2, 3, and 1. The order for each child was randomly determined, so that approximately half of the children in each of the groups received the tests in each of the given orders.

The subject matter test, consisting of 20 items covering the content of the six lessons, was presented immediately after the conclusion of the two week instructional period. This test was administered by the same person who had given the individual tests, but had not participated in the experimental program. The children were required to mark the correct response to each item in a booklet. One practice item was presented prior to the 20 subject matter items to insure that the children understood the marking procedure. After completing the posttest, the experimental children were given three additional items designed to assess their feelings

[1]See Appendix B for detailed descriptions of these four tests.

about the unit. There were a total of 21 points possible on the 20 item test. The test items are presented in Appendix B.

Results

The subject matter test was administered to 23 experimental and 17 control children. Out of a possible score of 21, the mean score of the instructed group was 10.8 (S.D. 3.1) while the control group obtained a mean of 8.5 (S.D. 2.6). The t-test on the difference between the group means was significant at the .01 level ($t=2.49$), favoring the instructed children.

The Fisher Test was used to analyze the difference in the proportions of experimental and control children who made correct and incorrect responses to each of the 20 test items. The results of these tests indicated that for six of the 20 items (i.e., Items 5, 8, 11, 12, 15, and 19), significantly ($p<.05$) more correct responses were made by the experimental group.

Because not all children in the experimental group were present for all six lessons, it was of interest to determine the relationship between the number of lessons received and subject matter test scores. The average number of lessons attended by the 23 instructed children who took the test was 4.8 (S.D. 1.3; range 2 to 6). The correlation of attendance with test performance was -.07, indicating that there was virtually no relationship between the number of lessons for which a child was present and the test score he achieved.

However, in the experimental group, test performance was related to whether or not a child had been pretested with the individual battery. Seven of the eight pretested children (Group 1) and 12 of the 13 non-pretested children (Group 3) took the subject matter test. The mean score

of Group 1 was 13.3 (S.D. 2.0), and Group 3 achieved a mean score of 10.2 (S.D. 2.8). The difference between the group means was significant ($t=2.6$, $p<.025$). In contrast, the mean scores for the two control groups did not differ (Group 2 $\bar{X}$ = 7.8, S.D. = 4.2; Group 4 $\bar{X}$ = 8.6; S.D. = 2.1).

In response to the questions designed to determine how the experimental group felt about the lessons, 78% of the children said they liked doing experiments with the instructor (Question 21) and that they would like to do more experiments with their own teacher (Question 23). Also, 87% said they wanted to learn more about atoms and molecules. Clearly, the children expressed positive feelings about the instructional program.

The means and standard deviations on each of the individual tests for Groups 1-4 are presented in Table 2. To determine if there were differences between the experimental and control children prior to instruction, comparisons of the pretest scores of Groups 1 and 2 were made for the Curiosity Box Test, the Ball Drop Test, the Liquid Change Test, and the three scores of the Floating Bodies Test. Each of the six t-tests indicated that there were no differences between the two groups prior to instruction. There was a large, though not statistically significant, difference between the Peabody Picture Vocabulary Test I.Q. scores of the two groups (Group 1 $\bar{X}$ = 94.4, S.D. = 19.5; Group 2 $\bar{X}$ = 79.6, S.D. = 26.0). However, the correlation between I.Q. scores and each of the individual test scores were low and statistically non-significant (range: -.30 to .28), indicating there was no relationship between intellectual functioning, as measured, and the individual tests.

For each of the four individual measures, the posttest scores were cast in a two-by-two analysis of variance with testing condition (i.e.,

TABLE 2

Individual Test Means and Standard Deviations

for Pretested and Non-Pretested Experimental and Control Groups

		Curiosity Box		Ball Drop		Liquid Change		Floating Bodies					
								Prediction		Verification		Re-sorting	
Group		$\overline{X}$	S.D.	$\overline{X}$	S.D.	$\overline{X}$	S.D.	$\overline{X}$	S.D.	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Pretested													
Experimental Group 1 (N=8)	Pre	13.0	6.5	2.4	1.1	3.4	2.1	5.8	0.7	7.5	0.8	7.5	0.8
	Post	16.3	4.4	3.1	0.8	4.6	1.7	6.5	1.3	7.9	0.4	7.9	0.4
Control Group 2 (N=8)	Pre	18.6	6.5	2.9	0.6	3.0	1.3	6.1	1.6	7.5	0.8	7.4	1.1
	Post	28.6	7.9	3.3	1.2	4.3	1.8	6.8	1.2	7.6	0.7	7.6	0.7
Total (N=16)	Post	22.4	8.9	3.2	1.0	4.4	1.7	6.6	1.2	7.8	0.6	7.8	0.6
Non-Pretested													
Experimental Group 3 (N=13)	Post	20.8	6.3	2.8	1.1	3.4	1.4	5.1	1.1	7.2	1.4	7.3	1.4
Control Group 4 (N=15)	Post	13.5	7.7	2.3	0.9	2.9	0.4	5.2	1.0	7.7	0.6	7.6	0.6
Total (N=28)	Post	16.9	7.8	2.6	1.0	3.1	1.0	5.1	1.0	7.5	1.1	7.5	1.0

pretesting or no pretesting) as the first factor and treatment group (i.e., experimental or control) as the second factor. A summary of these analyses of variance is presented in Table 3.

For the Curiosity Box Test, testing condition had a significant effect upon performance in that the pretested children achieved a higher mean score than the non-pretested children. In addition, there was a significant interaction between testing conditions and treatment groups. Newman-Keuls tests of the differences between pairs of means revealed that Groups 1, 2, and 3 each obtained a significantly higher mean Total Score than Group 4. That is, both of the experimental groups and the pretested control group scored higher than the non-pretested control group on the Curiosity Box Test. There were no other differences between the mean scores of the four groups.

On the Ball Drop Test, there were no significant effects due to testing or treatment condition; likewise, no significant interaction was found. However, this result may have been due to the restricted range of possible scores (0-4) on the test and the relatively high means of the four groups.

Results of the analysis of variance on the Liquid Change Test scores showed that the pretested children obtained a higher mean score than the non-pretested children. Similarily, on the Prediction score of the Floating Bodies Test, the analysis indicated that the pretested children outperformed the non-pretested children. There were no differences between groups on the Verification and Re-sorting scores of the Floating Bodies Test.

Test-retest reliabilities were computed for Groups 1 and 2, separately and combined, on each of the individual measures (Table 4). These

TABLE 3

Summary of Analyses of Variance for Individual Tests

		Curiosity Box Test		Ball Drop Test		Liquid Change Test		Floating Bodies Test					
								Prediction		Verification		Re-sorting	
Source of Variance	df	Mean Square	F	Mean Square	F	Mean Square	F	Mean Square	F	Mean Square	F	Mean Square	F
Testing	1	287.6	6.2*	3.6	3.7	17.5	10.3**	22.5	17.7**	1.0	1.1	1.0	1.1
Treatment	1	65.4	1.4	0.4	0.4	2.0	1.2	0.4	0.3	0.3	0.3	0.0	0.0
Testing x Treatment		983.8	21.1**	1.0	1.0	0.1	0.0	0.4	0.0	1.7	2.1	0.7	0.9
Error	40	46.7		1.0		1.7		1.3		0.8		0.8	

*p<.05; **p<.01.

TABLE 4

Test-Retest Correlations on Individual Measures for Groups 1 and 2

	Group 1 (N=8)	Group 2 (N=8)	Total (N=16)
Curiosity Box Test	.54	.78*	.72**
Ball Drop Test	.10	.43	.24
Liquid Change Test	.13	.03	.11
Floating Bodies Test Prediction	-.31	.89**	.45
Verification	.80*	.64	.63**
Re-sorting	.80*	.75*	.74**

*p<.05; **p<.01.

TABLE 5

Intercorrelations Among Curiosity Measures for Groups 1-4

	Group 1 (N=8)		Group 2 (N=8)		Group 3 (N=13)	Group 4 (N=15)
Measures	Pre	Post	Pre	Post	Post	Post
Curiosity Box Test-Ball Drop Test	.88**	-.36	.16	.61	.53	.34
Curiosity Box Test-Liquid Change Test	-.33	.58	.37	.45	.63*	-.03
Ball Drop Test-Liquid Change Test	-.07	.04	.17	-.03	.69*	-.30

*p<.05; **p<.01.

correlations for the Curiosity Box Test were high and reached significance for Group 2, and Groups 1 and 2 combined. The correlations were relatively low for the Ball Drop and Liquid Change Tests, which may have been due to the restricted range of the tests and the fact that most children scored high on the pretest as well as on the posttest. On the Prediction score of the Floating Bodies Test, there was a marked discrepancy between the correlation for Group 1 and Group 2. However, on the Verification and Re-sorting scores, the test-retest correlations were generally high (greater than .60) and reached statistical significance.

The correlations among the three curiosity measures for each of the four groups are presented in Table 5. For each of the three sets of correlations, the coefficients varied substantially from pretest to posttest with Groups 1 and 2, and across the four groups on the posttest, suggesting that testing conditions and treatment groups might have substantially affected the stability of the coefficients.

Discussion

It is clear from the results of the subject matter test that, in a relatively short period of time, the children did learn some important concepts related to atoms and molecules. In addition, they were greatly interested in the subject matter, and their responses throughout the instructional program as well as to Items 21 through 23 of the subject matter test indicated their enthusiasm and desire for continued instruction.

The results of the individual tests make it difficult to determine the effect of the instructional program on the children's attitudes. This seems to be primarily due to problems with the measures themselves.

Performance on the posttests was greatly influenced by whether or not the child had been pretested. In addition, the intercorrelations among the tests for the four groups as well as the test-retest correlations suggest that there is considerable noise in the measures. This is supported by records of the tester in which it was noted that factors outside the testing situation or treatment condition seemed to influence the test results. Specifically, the high posttest performance of Group 2 seemed be influenced by the fact that on the day the children were tested, a substitute teacher was in charge of the class, and the children were very excited about this novel situation. It may be that an increase in their general level of excitation or arousal influenced their curiosity behavior in a way that served to differentiate them substantially from the other relatively unaroused groups.

There is also a serious question as to whether or not these measures contained a range of activities such that the children could demonstrate changes in behavior. This would seem to be a difficulty for the Ball Drop Test, Liquid Change Test, and the Floating Bodies Test. The Curiosity Box Test did not impose a scoring ceiling on the children. Yet it is the case that Groups 1 and 4, which had the highest mean I.Q. scores (94.4 and 91.8, respectively), showed the least curiosity behavior whereas Groups 2 and 3, which had lower mean I.Q. scores (79.6 and 83.4, respectively), demonstrated the most curiosity behavior. Thus the test may not be appropriate for children above the mental age of 5 to 6 years. Banta's original work with the test (1966, 1967) was carried out with children between the chronological age of three and six. The results of the present study suggest that children above the mental age of 5 to 6 years may score poorly on the test because the box no longer arouses their curiosity.

In sum, the subject matter of the instructional program was of great interest to the children. Study of the video-taped records of the six classes suggested ways in which the effectiveness of the lessons could be increased, and it seemed desirable to see whether the children would show further improvement in the development of scientific procedures and attitudes following a revised and longer course of study. Accordingly, the work of the two-week program was extended and is presented in Part II below.

Part II

Method

Subjects

The same experimental and control children participated in the second part of the study. (See Part I for a complete description of the groups.)

Instructional Program

Approximately one month after the completion of the two-week program described in Part I, this second phase of the instruction began. A total of five 30-minute lessons were presented in a seven-week period to the experimental children by the same biochemist who conducted the previous two-week program. During the periods between each of the lessons, the regular classroom teacher conducted two 30-minute sessions which were based on the material presented by the biochemist.

The instructional program consisted of an introductory class discussion of what happens when molecules are eaten, followed by three lessons focusing on (1) molecular model building and (2) the relationship between chemical equations, as symbolic expressions of molecular reactions, and actual chemical reactions during which molecules can undergo changes.

The fifth lessons emphasized scientific logic. The contents and activities of these five lessons are described more fully in Appendix A.

Criterion Measures

Two testers who had had no previous contact with the experimental and control children administered the posttest one week after the completion of the instructional program. The children were tested in groups of five (three experimental and two control). The treatment groups of the children were unknown to the testers, each child being identified by a random code. During testing, the children were seated at tables, and dividers were used to separate them. However, isolation was not complete, and a child occasionally made comments which could be heard by other children. A total of eight groups of five children each (i.e., 24 experimental and 16 control children) was tested in one day.

The test consisted of 10 questions covering the concepts taught.[2] However, only the first six were included in the evaluation because the scoring of the last four questions was considered by the testers to be unreliable. Two items unrelated in content to the instructional program were presented prior to the 10 questions and served only as an introduction to the test.

Items 1-3 dealt with the concept of molecular size and were each scored one or zero for correct or incorrect, respectively. The children's understanding of molecular models was tested with items four and five, and item six tested their understanding of the logic of chemical experiments. Items 4-6 were based upon a molecule and enzymatic reaction which had not been mentioned or shown in any class session. Each of these items

[2]The test items are presented in Appendix B.

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was scored zero for incorrect, one for partially correct, and two for completely correct. Thus, on the test there were nine points possible.

Results

The posttest means and standard deviations of the experimental and control groups are presented in Table 5. The experimental group performed consistently better than the control group on the total test as well as on each of three subscores. Analyses of these differences between the groups indicated that the experimental group attained significantly higher scores than the control group on the total test ($t=3.0$, $p<.005$) and the molecular size subscore ($t=2.5$, $p<.01$).

This superior performance on the total test of the instructed over the control group is consistent with the findings on the subject matter test of Part I, although the tests differed in many respects. The concept of molecular size was tested with both instruments, and it should be noted that on both tests the experimental group performed significantly better than the control group on those items (i.e., Part I, Item 15; and Part II, Items 1-3 subscore).

Again, the correlation of Peabody Picture Vocabulary Test IQ scores with test performance was found to be nonsignificant for both the experimental ($r=.46$, $N=15$) and control ($r=.06$, $N=12$) groups.

Discussion

The posttest results revealed that the experimental children continued to perform better than their control counterparts under the revised instructional program. Although their grasp of the concepts of molecular models and experimental logic fell short of the goals of the

TABLE 5

Posttest Total Score and Subscore Means and Standard Deviations

for the Experimental and Control Groups

Posttest	Experimental (N=24) $\bar{X}$	Experimental (N=24) S.D.	Control (N=16) $\bar{X}$	Control (N=16) S.D.
Total Score (Items 1-6)	4.5	1.8	2.8	1.8
Subscores				
Molecular Size (Items 1-3)	2.3	1.0	1.5	1.1
Molecular Models (Items 4-5)	1.0	1.1	0.4	0.5
Experimental Logic (Item 6)	1.2	0.6	0.9	0.8

program, they did seem to demonstrate some facility with these most difficult and abstract notions.

What is important to note is that, in contrast to the Part I program which was conducted entirely by a trained biochemist, the Part II instructional program was presented only in part by the biochemist. Instead, a large portion of the instruction was given by the regular classroom teacher who was untrained in the subject matter of biochemistry and who received only minimum instruction from the biochemist as to how to conduct the practice lessons given in his absence. This suggests that similar science modules might be introduced into school curricula without a subject matter expert replacing the regular classroom teacher or extensive training of the regular classroom teacher. Rather, through a procedure of modeling coupled with minimum instruction, a subject matter expert can work with a classroom teacher on a limited basis to introduce complex and exciting concepts to children who otherwise would not be so stimulated.

The two units presented in Parts I and II represent but first attempts toward the development of instructional programs designed to improve young children's scientific inquiry processes. It is clear that future research efforts should be concerned with reformulating the descriptions of behaviors to be developed and in refining instruments for assessing changes attributable to various types of interventions.

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Appendix A: Instructional Program

Part I

Lesson 1.

The children were introduced to the concept that everything is made of molecules and that molecules, in turn, are composed of atoms. Numerous examples of different substances were given and, in each case, it was pointed out that different substances are made of different kinds of atoms and molecules.

The following analogy was then presented: atoms : molecules = letters : words. Children participated in making specific words from given sets of letters. They practiced making "molecules" from atoms, which were symbolized by letters.

Lesson 2.

After reviewing the relationship between the size of atoms and molecules, the children were introduced to the notion that everything is made of about 100 kinds of atoms which vary in size.

Three different kinds of substances were then presented along with the molecular model for each:

(1) dry ice (O-C-O); (2) water (H-O-H); and (3) chalk (X-O-C-O-X).[3]

The children were asked: (1) "How many atoms are there in each molecule?" (2) "How many kinds of atoms are there in each molecule?" (3) "How many O atoms, C atoms, etc., are there in each molecule?"

During the lesson the children were shown four boxes, each coded by a different color and containing one of the three molecules previously discussed. Each child was invited to examine the boxes for the purpose of locating the box containing the O-C-O (i.e., the dry ice). Once he had decided on the box, he was asked to record the color of the correct box on a sheet of paper provided. The kinds of cues that could have been used to identify the box of O-C-O were discussed and the correct location of the O-C-O was then determined by the class.

Lesson 3.

Again there was review and discussion of the concepts of size and kinds of atoms and molecules, with special attention to the molecules O-C-O, H-O-H, and X-O-C-O-X, and the substances they represented. An attempt was made to synthesize chalk (X-O-C-O-X) from O-C-O and H-O-H by blowing into a tube of water. The failure of this experiment generated

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[3] In Part I, the branching formula for chalk ($\mathrm{X\text{-}O\text{-}\underset{\displaystyle O}{C}\text{-}O\text{-}X}$) was actually used whereas in Part II, it was simplified to X-O-C-O-X. While neither of these formulae are technically correct, they are close enough and were used for convenience in developing subsequent experimental sessions.

a discussion which pointed up the need for X molecules. The correct formulation was presented on the blackboard.

A demonstration-laboratory session involving eight children, four at a time, followed. Each child had before him test tubes, glass pipettes, a bottle of X atoms, and a tube of alkaline H-O-H. (Special caution and close supervision were required in the use of the dilute alkali.) The task was to try to synthesize chalk. The session allowed for individual experimentation as well as small group discussion of the outcomes of experimentation.

Lesson 4.

The laboratory session of Lesson 3 was reviewed. An important aspect of this part of the review was to encourage the children to speak out, challenge when they help opposing points of view, and observe evidence carefully. As an illustration of this point, they were asked to do the impossible; that is, four children were asked to blow into a tube of water when no water was provided.

These same children were then given water and asked whether they thought they could make chalk according to the following equation:

$$\text{O-C-O} + \text{H-O-H} \xrightarrow{?} \text{X-O-C-O-X}$$

After they had made their guesses, they were asked to try the experiment in front of the class and evaluate whether their guesses had been correct or incorrect.

The instructor then demonstrated the synthesis of chalk according to the following equation:

$$\text{O-C-O} + \text{X-O-H} \longrightarrow \text{X-O-C-O-X} + \ldots$$

The idea of building bigger molecules from smaller ones was developed using anagrams as molecular models with selected children participating in front of the class.

A new molecule, similar to chalk, was introduced: R-O-C-O-H[4] (baking soda). The solubility properties of baking soda and chalk were compared. The conversion of R-O-C-O-H to chalk upon the addition of X molecules was demonstrated by the instructor. Several students then conducted this same experiment. That is, they made guesses as to what would happen when X molecules were combined with R-O-C-O-H, then performed the experiment, and evaluated what really did happen during the experiment.

Lesson 5.

The variable of speed of molecular change was introduced and discussed, using as one example the slow ripening of bananas, with the corresponding molecular reaction in the banana skin that results in the visible color change of the skin from yellow to black. A second example of a slow reaction was the changing of the colors of leaves. As an example of a fast

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[4] In Part I, the branching formula for baking soda ($\text{R-O-}\underset{\text{O}}{\underset{|}{\text{C}}}\text{-O-H}$) was actually used. In Part II, the formula was simplified: R-O-C-O-H.

reaction, the conversion of baking soda to CO_2 by the addition of vinegar (H-A) was presented.

Molecular size and properties were reviewed using vinegar (H-A) and rubbing alcohol (R-C-O-H) as examples. Throughout this session, the children were encouraged to formulate hypotheses, ask questions, make guesses, request better views or closer contact so that they could see or smell the molecules which were presented to them.

The second half of the lesson was devoted to a laboratory session in which all children participated. Each child was given four tubes, each labeled with four different molecular formulae corresponding to the kind of molecules in the tubes. They were then presented with four hypothetical ways of making chalk molecules. These possibilities were presented as chemical equations on the blackboard. The students were asked to guess which equation was correct and to try to make chalk according to each of the equations. They were asked to indicate (1) their guesses before the experiment, and (2) the correct equation after completion of the experiment.

Lesson 6.

Students were presented with four tubes, each of which contained a different kind of molecule. They were asked to guess which tube contained R-O-C-O-H molecules and then to record their guesses on a sheet provided them.

The concept that large molecules can be broken down into smaller molecules was introduced. The example used was the breaking down of baking soda molecules:

(1) R-O-C-O-H + H-A $\longrightarrow$ H-O-C-O-H + R-A; and
(2) H-O-C-O-H $\longrightarrow$ H-O-H + O-C-O

The experiment demonstrating this reaction was performed by the instructor. Special emphasis was placed on the fact that O-C-O gas is formed from the R-O-C-O-H during the reaction and the students were told that this property of R-O-C-O-H could be used to tell which tube had the R-O-C-O-H and whether their guesses were right or wrong. The students were asked to use this information to determine experimentally whether or not their guesses were correct.

The class ended with a brief review of the ability of certain molecules to change into larger or smaller molecules when they react with each other.

Part II

Lesson 1.

Two imaginary mice were "shown" to the class: a large mother mouse and her small baby mouse. The following questions were raised by the

instructor: "Which mouse has more molecules? Where do the extra molecules in a mouse come from when a small mouse turns into a big mouse? What do you think happens when a mouse eats some sugar molecules?" These questions led to a discussion of the differences among the terms "in the mouth," "in the stomach," and "in the body." A molecular model of a sugar molecule was drawn on the board, and the children were asked, "What do you think happens to a sugar molecule when it gets into the body" The formation of water (H-O-H) and O-C-O from sugar molecules was discussed using molecular models on the blackboard.

Lesson 2.

This lesson focused on molecular model building. The children were provided with variously colored wooden beads, representing different atoms, and wooden connecting sticks with which to build the molecular models. First, they were asked to try to make some molecules. No restrictions were placed on the size or the nature of the molecules. Students were asked, "How many atoms are in your molecule?" Next, they were told to make molecules with a specific number of atoms and were asked, "How many different kinds of atoms do you have in your molecule?" Finally, they were told to construct molecules with two of the same kinds of atoms and three different atoms. Much individual attention was given to the children by the instructor during these activities.

The children were then presented with some activities to work on with their teacher during the following week. They were told that they were to practice making molecules with their beads, and that their teacher would help them. The specific molecules they were to practice making and the color codings for the atoms involved were presented on the blackboard:

ATOMS	MOLECULES
H = red	H-O-H
O = yellow	O-C-O
C = purple	X (an atom)
X = blue	X-O-C-O-X
R = green	R-O-H
	H-O-C-O-R

When building these molecular models, the children were told to think about how many atoms and how many different kinds of atoms there were in each molecule.

Lesson 3.

Beads and connecting sticks were again distributed. Children started making molecular models without being told to do so. As in the previous week's lesson they were asked individually, "How many atoms and how many kinds of atoms are in your molecule?" The instructor assigned new color symbols for the atoms given at the end of Lesson 1, and he asked the students to make H-O-H, O-C-O, R-O-H and X-O-H molecules. The class spent the rest of the lesson making the above four molecules. Again, the children were given considerable individual attention. The teacher was

asked to continue this activity during the next week, using a different color code to represent the various atoms.

Lesson 4.

This lesson began with a continuation of molecular model building. Different atoms were symbolized by colored paper squares, which the children had made, rather than by colored beads as in previous lessons. The children were asked to build the molecule R-O-C-O-H. Then they were asked to make "chalk molecules," (X-O-C-O-X) from R-O-C-O-H + X + X as shown by the following reaction which was written on the blackboard:

(1) R-O-C-O-H + X + X $\longrightarrow$ X-O-C-O-X + R + H

In referring to this reaction, the instructor stated, "Here is the idea of what we are going to do with real molecules." Then the real reaction was carried out as a demonstration. The demonstration was repeated by several volunteer students in front of the class. Before each experiment individual students were asked if they thought chalk would form when R-O-C-O-H and X atoms were mixed together. They were told repeatedly, "It doesn't matter if your guess is right or wrong as long as you find out what really happened." They were asked if they had guessed correctly or not. Then the class was shown two other reactions on the blackboard using molecular models:

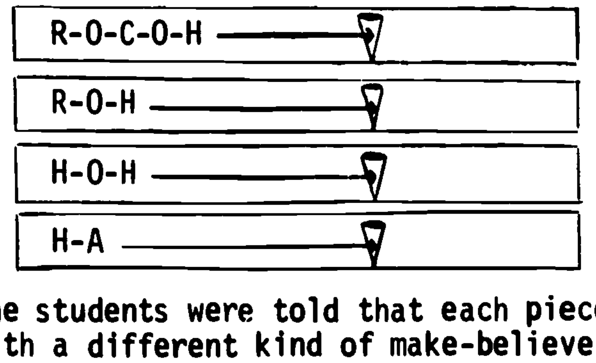
(2) X-O-C-O-X + HA $\longrightarrow$ O-C-O (bubbles) + [something]

(3) R-O-C-O-H + HA $\longrightarrow$ O-C-O (bubbles) + [something]

Each reaction was actually demonstrated. [The chemical reaction (2) was subtle using the X-O-C-O-X that had been formed in reaction (1), but dramatic with the dry R-O-C-O-H in reaction (3).] The regular teacher was then asked to continue this work during the next week. It was suggested that groups of five or six children at a time should try all of the experiments that had been demonstrated in the class using both the ideas of molecules (molecular models) and the real molecules.

Lesson 5.

Each child was given four pieces of paper, each with a molecular formula and a picture of a tube:



The students were told that each piece of paper was a make-believe tube with a different kind of make-believe molecule. Then chemical equations

were put on the board, one at a time. For example:

$$\text{R-O-H} + \text{H-O-H} \xrightarrow{?} \text{O-C-O (bubbles)} + \ldots$$

For each equation, the class was then asked the following questions: "Do you think that if you mix R-O-H molecules with H-O-H molecules that you will get O-C-O molecules, that is, O-C-O bubbles? Suppose that you were going to do the experiment, what two tubes would you take to do the experiment? Do you know how to do the experiment to find out if...?"

The children were given the opportunity to select the two correct pieces of paper which corresponded to R-O-H and H-O-H. The instructor brought out four tubes, each containing the molecules which corresponded to the above four pieces of paper. He said that he was going to do an experiment to see if the following was true:

$$\text{R-O-H} + \text{H-O-H} \xrightarrow{?} \text{O-C-O (bubbles)}$$

The instructor purposely selected the wrong tubes to allow students to challenge the incorrect statements. He then carried out the experiment correctly and asked the students if their guesses were right or wrong: "Can you make O-C-O bubbles from R-O-H and O-C-O?" The above approach was repeated with three other examples:

$$\text{R-O-H} + \text{R-O-C-O-H} \xrightarrow{?} \text{O-C-O} + \ldots$$

$$\text{R-O-C-O-H} + \text{H-O-H} \xrightarrow{?} \text{O-C-O} + \ldots$$

$$\text{R-O-C-O-H} + \text{H-A} \xrightarrow{?} \text{O-C-O} + \ldots$$

Some of the children were asked to try the experiments in front of the class. The teacher was asked to continue this work during the next week so that all of the children could use their own <u>real</u> tubes and <u>real</u> molecules.

Appendix B: Criterion Measures

Part I

Individual Tests.

The Curiosity Box from the Cincinnati Autonomy Test Battery was used to assess the amount and quality of curiosity (or exploratory behavior) demonstrated by a child. The box is colorfully decorated and has attached to its inside and outside walls many attractive stimuli which allow for a variety of exploratory behavior on the part of the child.

The specific procedure for administering the Curiosity Box Test is outlined by Banta (1968, pp. 19-21). The tester introduces the box and invites the child to play with it. Taking a position to the side and behind the child, the tester records the child's activities and verbalizations over a five minute observation period which, for purposes of recording, is divided into 10 30-second intervals. There are five categories of exploratory activity which are defined in terms of the specific attributes of the box: (1) manipulatory exploration, (2) tactual exploration, (3) visual exploration, (4) movement by the subject, and (5) movement of the box. Within each half-minute observation interval, one point is given for the occurrence of each type of exploration. Thus, the maximum activity score of 50 could be attained if, within each interval, a child engaged in all five types of exploration. Two categories of verbalization are also recorded: (1) box-related and (2) other. Within each of these categories, a further division is made between (a) questions and/or comments, and (b) fantasy verbalizations.

It should be noted that Banta's original work with the Curiosity Box Test (1966, 1968) was carried out with lower class Negro children between the ages of three and six. While the present study was also conducted with a similar income group, the children were older (mean age approximately six-and-a-half years) and primarily Mexican-American. However, preliminary work with the test indicated that these children scored considerably below the ceiling of 50 points, and thus the test could be used for this study.

Two more tests were devised to assess curiosity behavior in young children: (1) Ball Drop Test and (2) Liquid Change Test. Both tests were designed to determine if a child would perform a simple manipulation (e.g., uncover a hidden object) in order to observe the consequence of some action. The assumption was that it would take a certain degree of curiosity to do so.

In the case of the Ball Drop Test, the consequence of an action performed by the child was not directly demonstrated to him but rather had to be inferred from a previous similar demonstration by the tester. More specifically, the tester demonstrated that by drawing on a piece of carbon paper a mark would appear on the piece of white paper beneath it (i.e., the tester lifted the carbon paper to show the child the mark). From a height of from six to eight inches the tester dropped a one-inch

diameter steel ball onto a sheet of carbon paper. Without showing the child the consequences of this action (i.e., the marks made on the paper), the child was invited to drop the ball on his own carbon paper. The tester recorded whether the child (1) dropped the ball, (2) looked under the carbon paper to see what happened, (3) extended the activity in any way (e.g., tried to make different patterns on the paper, altered the height from which the ball was dropped, etc.), and/or made comments or asked questions related to the testing situation. All children were encouraged to drop the ball. A 15 second time limit was placed on the test. If at the end of this time period the child had dropped the ball but had not looked under the carbon paper, he was given a prompt: "What happened? What did you do?" The tester recorded whether the child (4) looked under the carbon paper, and (5) extended the activity in any way and/or made comments or asked questions related to the testing situation.

4 points: Activities 1, 2, and 3
3 points: Activities 1 and 2
2 points: Activities 1, 4, and 5
1 point: Activities 1 and 4
0 points: Activity 1 or no activity

For the Liquid Change Test, one consequence of an action was demonstrated by the tester, but when the child performed what appeared to be the same action, a different consequence ensued. That is, two test tubes were placed before the child, one wrapped in foil, the other not. The child was told that his tube was the one wrapped in foil, the other being for the tester. In the tester's tube was a small amount of a dilute solution of the base K-O-H, a clear liquid. In this tube the tester put a drop of another clear liquid, phenolphthalein. When phenolphthalein and K-O-H are mixed, the solution turns a reddish-purple. Thus, the liquid in the tester's tube changed color. The tester then asked the child if he too would like to try the experiment. The tester helped the child squeeze a drop of phenolphthalein through the small hole in the top of his covered tube. However, because there was no K-O-H in the tube, the liquid did not change color. The tester recorded whether the child (1) asked to or actually did uncover the tube prior to adding the phenolphthalein, (2) uncovered the tube after adding the pehnolphthalein, (3) commented or asked questions about the lack of correspondence between the tester's tube and his own, and/or engaged in activities extending the testing situation. There was a 15 second time limit on the test, commencing once the phenolphthalein had been added to the child's tube. At the end of this time period, if the child had not uncovered the tube or asked permission to do so, he was prompted: "What happened?" If the child still did not uncover the tube, he was prompted: "Would you like to uncover it?" Following these prompts, the tester also recorded whether the child (4) predicted what had happened, (5) uncovered the tube, and (6) commented or asked questions, and/or engaged in activities extending the testing situation.

A total of seven points were possible, and the child was scored as follows:

7 points:	Activities 1 and 3
6 points:	Activities 2 and 3
5 points:	Activity 1
4 points:	Activity 2
3 points:	Activities 4, 5, and 6
2 points:	Activities 4 and 5, or 5 and 6
1 point:	Activities 4 or 5
0 points:	No activity

The fourth individually administered test was the Floating Bodies Test. As described by Inhelder and Piaget, 1958, p.20), the procedure is as follows:

> A given number of disparate objects are presented to the subject, who is asked to classify them according to whether or not they float on water. Then (the classification completed) he is asked to explain the basis of his classification in each case. Next, the subject himself experiments, having been given one or several buckets of water; finally, he is asked to summarize his observations, this latter request suggesting that he is to look for a law, if this has not already spontaneously occurred to him.

Thus, for Inhelder and Piaget, the purpose of presenting this problem was to establish the developmental stages through which children progress in the understanding and formulation of the law of floating bodies. The authors have shown that children cannot formulate this law until the ages of 11 to 13 years. Indeed before the ages of seven to eight years, the authors maintain that children have great difficulty classifying the objects into floating and sinking groups after having observed their properties in the experiment (1958, p. 23).

The purpose of using this test in the present study was not to determine whether children could formulate the law of floating bodies. Rather it was used to assess six-year-old children's ability to (1) venture an hypothesis about something (i.e., guess whether each of eight objects would float or sink when put in a container of water), (2) conduct an experiment and observe the evidence (i.e., put the objects in a container of water and observe what happened to each), and (3) draw the appropriate inferences based on the evidence (i.e., classify the eight objects according to whether or not they actually did float when put in a container of water).

The objects used were: (1) a clay ball (1-1/2 oz., 1-1/2 inches diameter); (2) a cork ball (1/16 oz., 1 inch diameter); (3) a nail (1/16 oz., 5/8 inch long); (4) a flat rock (1 oz., approximately 1-1/2 inches diameter); (5) a shell (1/16 oz., 7/8 inches diameter); (6) a metal wire (1/16 oz., 2-5/8 inches long); (7) a wooden toothpick (1/16 oz., 2-3/8 inches long); and (8) a wooden stick (1/2 oz., 5 inches long, 3/8 inch diameter).

As an introduction to the problem, the tester sought to establish the child's familiarity with the phenomenon, and the corresponding terminology, of floating and sinking objects. A container of water, and the cork and clay balls were presented to the child, and he was asked to guess what would happen if the balls were put in the water. Once the guesses were made, each ball was put in the water and the child was asked to relate what happened to each. He was encouraged to use the terms "float" and "sink" to describe the object which "stayed on top" and the object which "went to the bottom," respectively. The objects were then removed from the water.

The problem itself was divided into three phases: (1) Prediction, (2) Verification, and (3) Re-sorting. During the Prediction Phase, the eight stimuli were presented and the child was asked to sort them into two groups: (1) those that would float and (2) those that would sink. Once they were sorted, the objects were put in the water and the child was asked to carefully note what happened to each. The objects were then removed, placed in one pile, and the child was asked to again sort them into floating and sinking groups on the basis of what he had observed. This constituted the Verification Phase.

The Re-sorting Phase of the problem was administered after the Ball Drop and Liquid Change Tests. At that time, the eight objects were presented to the child, and he was again asked to sort them into two groups on the basis of whether or not they would float when put in water. The purpose of the re-sorting was to determine the extent to which the child could remember what he had observed over a short period of time.

During each phase of the problem the child was scored for the number of objects, out of eight, he correctly identified in terms of floating and sinking. Thus the range of scores at each phase was from 0 to 8.

<u>Subject Matter Test Items</u>

1. Are molecules made of atoms?

2. Is one atom bigger than one molecule?

3. Is one drop of water bigger than one molecule of water?

4. Can you see one molecule of water?

5. Here is a molecule of O-C-O. When you blow out, are there O-C-O molecules in your breath?

6. Here are two molecules: H-O-H and O-C-O. Are they the same molecules?

7. Here are two molecules: X-O-H and H-O-H. Are they different molecules?

8. Here are two molecules: H-O-C-H and H-O-H. Are they made of the same kinds of atoms?

9. If you put this D-E molecule together with the K-L molecule, can you make the molecule D-E-M-N?

10. If you put this H-O-H molecule together with the O-C-O molecule, can you make the molecule X-O-C-O-X?
 O

11. Here is a molecule of K-O-H. Mark an X through one of the atoms in the molecule.

12. Here is a molecule of X-O-H. Mark an X through the H atom of the molecule.

13. Here are two molecules: H-O-H and H-O-O-H. Mark an X through the one that has the most atoms.

14. Here is a big molecule: A-B-E-F. Here are three smaller molecules: A-B, C-D, and E-F. Drawn an X through the molecules you need to make the A-B-E-F molecule.

15. Here is a molecule of O-C-O. Put an X in the box that tells you how many atoms there are in O-C-O.

16. Here is a molecule of H-O-O-H. Put an X in the box that tells you how many kinds of atoms there are in H-O-O-H.

17. Here are some different kinds of atoms: K, H, X, O. Draw a molecule that is made of two different atoms.

18. Here are the same atoms again. Draw a molecule that is made of three of these atoms.

19. Here are some different kinds of atoms: C, H, O, X, J, and T. Draw a molecule that has two H atoms and one O atom.

20. Here are the same atoms again. Draw a molecule that has one C atom, one J atom, and one O atom.

Note: Items 21-23 were given to the experimental class only.

21. Do you like doing the experiments with __________?

22. Would you like to learn more about atoms and molecules?

23. Would you like to do more experiments with your teacher?

Part II

Posttest Items

1. How many atoms are there in a molecule of H-O-O-H? Put a circle around your answer. (Choices: 0, 1, 4 and 3.)

2. How many O atoms are there in a molecule of H-O-O-H? Put a circle around your answer. (Choices: 0, 1, 4, and 3.)

3. How many H atoms are there in a molecule of H-O-O-H? Put a circle around your answer. (Choices: 0, 2, 4, and 1.)

4. You have some colored papers. (Each student has five each of yellow, green, and red pieces of one-inch square paper.) Let us say the red papers are H atoms. The green are O atoms. The yellow are X molecules. Look at this board. (These relationships are displayed on a card.) Now make a molecule of H-O-O-H. (Help after 1 minute.)

5. H-O-O-H is a molecule that is bigger than a molecule of H-O-H (water). (These molecules are presented on a card to the children.) X is a molecule that makes H-O-O-H turn into H-O-H and O↑ bubbles. X doesn't change at all when it bumps into H-O-O-H. If you bump a molecule of X into a molecule of H-O-O-H, you get H-O-H and O↑. (This reaction is diagramed on a card.) Can you show me this (point to reaction) with your colored papers?

6. Here are four tubes with four different kinds of molecules in them. (Tester reads labels: H-O-H, H-O-O-H, X, and R-O-H.) Show me the two tubes you would mix together to see if you can make O↑ bubbles. (The equation is indicated on a card. The tester records the answers and then shows the correct tubes and refers to equation card: "If you mix this and this you can make this.")

7. (Wait 15 seconds to see if they try to mix the tubes from Item 6. Record answers. Suggest they try it.) Would you like to...?

8. Do you think you can make more O↑ bubbles if you add more X molecules? Don't do it yet. First make a guess. Put a circle around <u>yes</u> if you think you can make more bubbles with more X molecules. Put a circle around <u>no</u> if you think you cannot make more O↑ bubbles.

9. (Pause and note responses.) Now try it.

10. Was your guess right or wrong? (Ask each child individually. Refer to Answer 8 if necessary. Note response.)